Climate Change and Renewable Energy
A Perspective from a Measurements Viewpoint

Regional Workshop on
Metrology & Technology Challenges ofClimate Change and Renewable Energy

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National Institute of Standards and Technology
U.S. Department of Commerce

Agenda

- **Renewable Energy**
  - Smart Grid
  - Energy Efficiency in Buildings
  - Photovoltaics
- **Greenhouse Gas and Climate Science Measurements**
  - Objective and Program Components
  - Selected Research

NIST EFFORTS IN SMART GRID, BUILDING ENERGY EFFICIENCY, AND PHOTOVOLTAICS

- Centered in NIST's Engineering Laboratory
- Strong Interactions with U.S. industrial sectors
  - manufacturing, building and construction, and infrastructure
- Standards development utilizes the rather unique U.S. consensus process and Standards Developing Organizations

NIST Engineering Laboratory

Research Objective and Vision

- **Objective:**
  Anticipates and meets measurement science and standards needs for technology-intensive manufacturing, construction, and cyber-physical systems, including the *Smart Grid Program Office*, in ways that enhance economic prosperity and improve the quality of life.
- **Vision:**
  Be the source for:
  - **Solution-enabling measurement science , and**
  - **Technical contributions underpinning emerging standards, codes, and regulations used by the U.S. manufacturing, construction, and infrastructure industries to strengthen leadership in domestic and international markets.**

NIST Measurement Science Research

Supporting U.S. Codes & Standards

- U.S. Codes and Documentary Standards are Publically Available both Nationally and Internationally
- Building Codes are Often Regulatory in Nature Involving Public Health and Safety Issues

Smart Grid

What is it in the U.S. ?

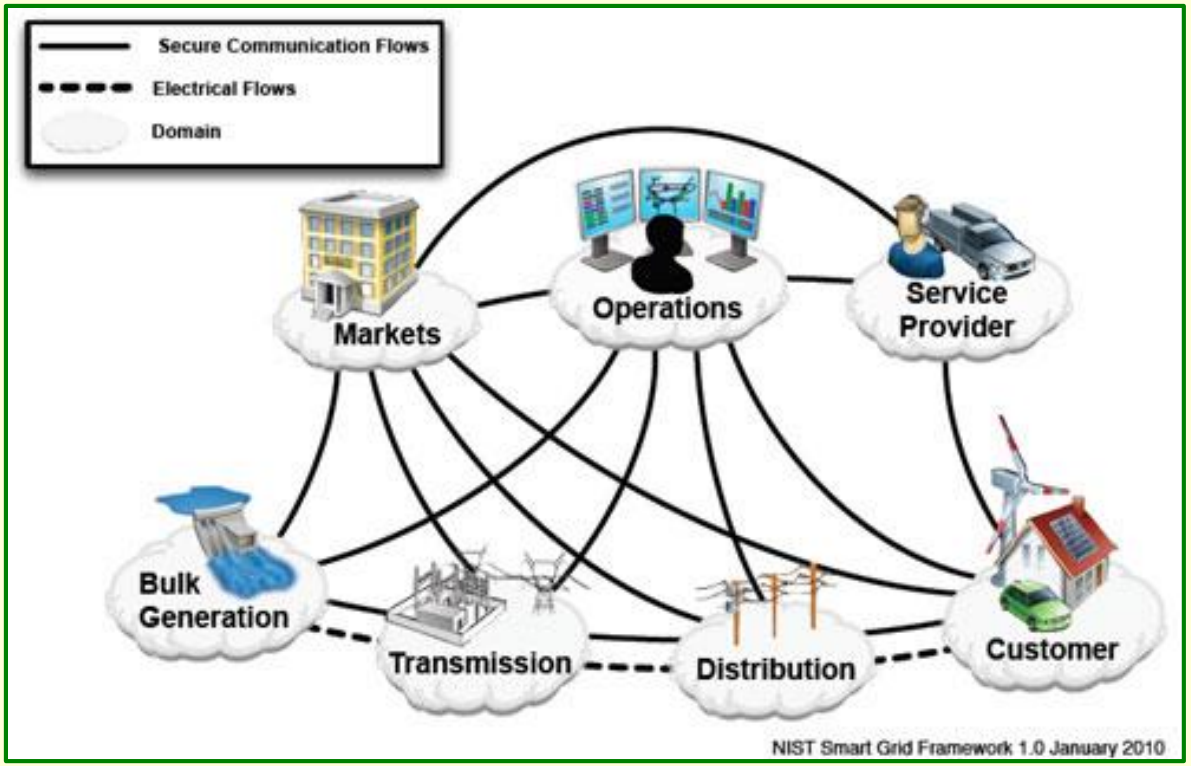
https://www.smartgrid.gov/

- "Smart grid" generally refers to a class of technology that will bring utility electricity generation and delivery systems into the 21st century
- The two-way communications technology and computer processing is the technological enabler
- Electricity delivery networks are being transformed
  - Enabling distributed generation – Some consumers are beginning to become producers
  - Benefits to utilities and consumers – significant improvements in energy efficiency on the electricity grid and in the energy users' homes and offices.

Smart Grid in the U.S.

A NIST Perspective

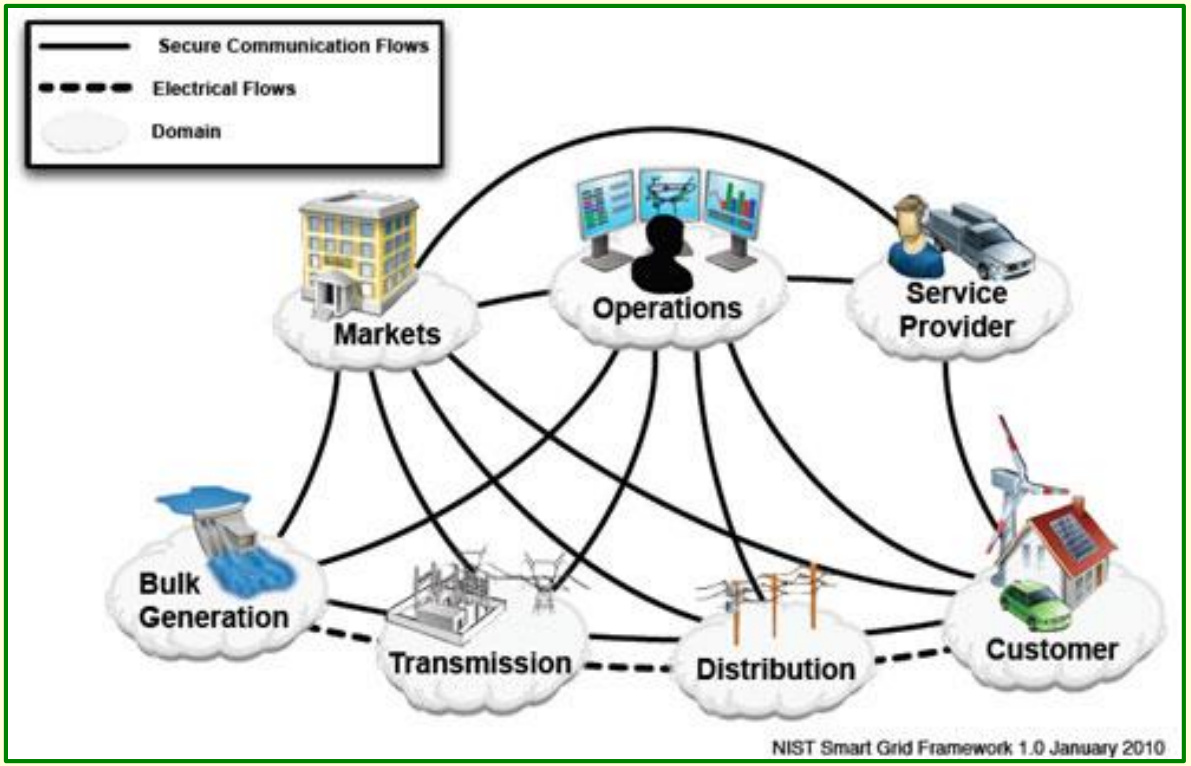
- The NIST Smart Grid Program aims to develop and deploy advances in measurement science to enable integration of interoperable and secure real-time sensing, control, communications, information and power technologies to increase efficiency, reliability and sustainability of the nation's electric grid.
- A documentary standards and measurements research effort.



Smart Grid in the U.S.

A NIST Perspective

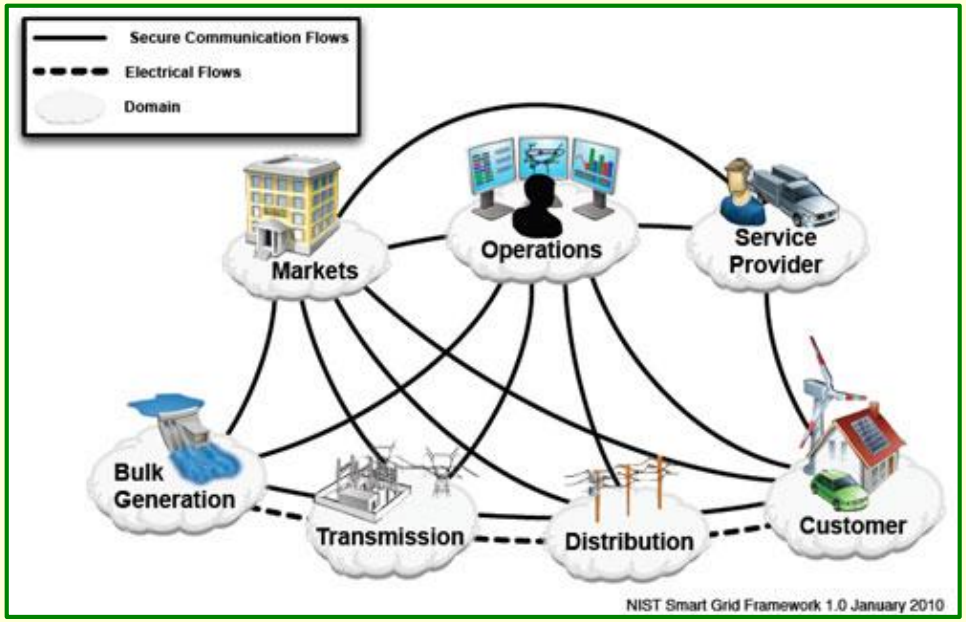
- The NIST Smart Grid Program aims to develop and deploy advances in measurement science to enable integration of interoperable and secure real-time sensing, control, communications, information and power technologies to increase efficiency, reliability and sustainability of the nation's electric grid.
- Promotes advances in cyber security and electrical metrology methodologies and standards for secure energy delivery



Smart Grid in the U.S.

A NIST Perspective

- **The NIST Smart Grid Program is a collaborative effort between U.S. industry and Government to establish advanced and secure energy delivery and generation**



- **U.S. Dept. of Energy leads the U. S. Government effort**
- **NIST has specific responsibilities for cyber security standards and for electrical metrology advances and standards**

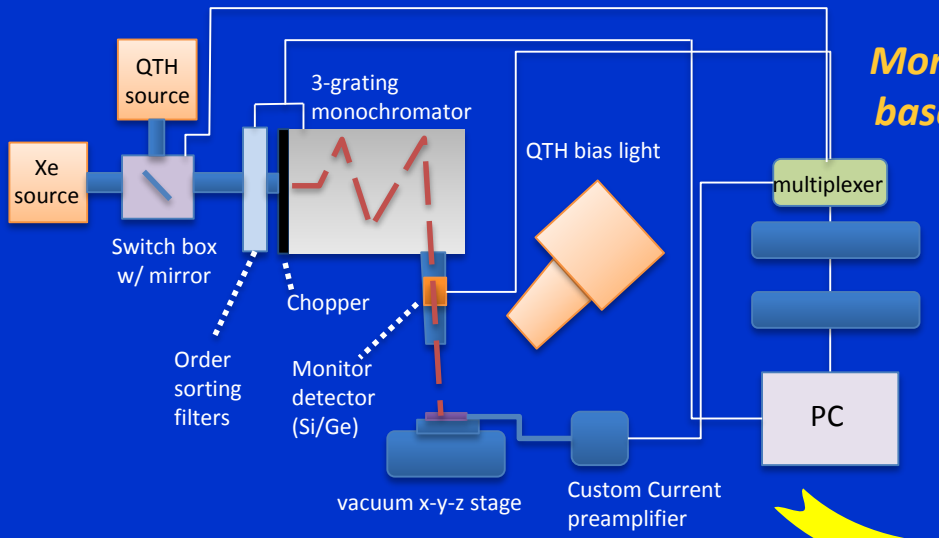
- **Many new capabilities are becoming available**
- **Countries and regions that wish to enable distributed electricity generation, such as solar and wind-driven electrical, have the opportunity to take advantage of these capabilities**
- **Standards efforts are advancing commercial availability and compliance with state-of-the-art electrical system characteristics.**

PHOTOVOLTAIC CELL & ARRAY PERFORMANCE METRICS

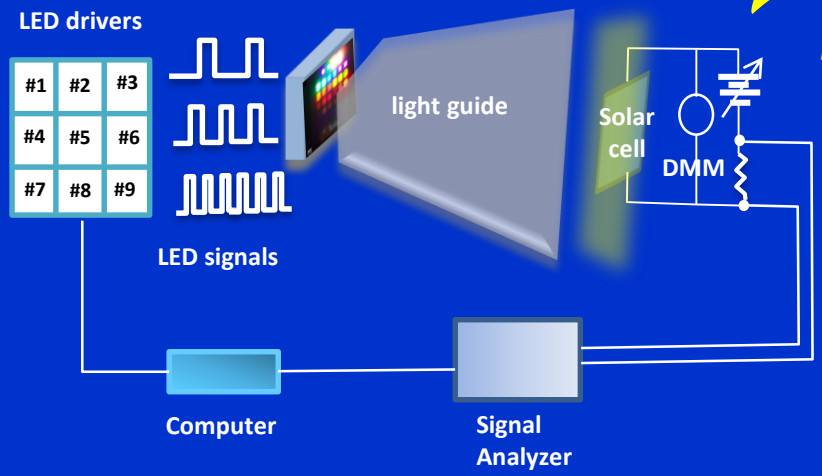
- Advancing Characterization Methods For Individual Cells
- Improving Panel Materials Failure Mechanism Models
- PV Panel Array Testing Methods

Solar Cell/Module Characterizations

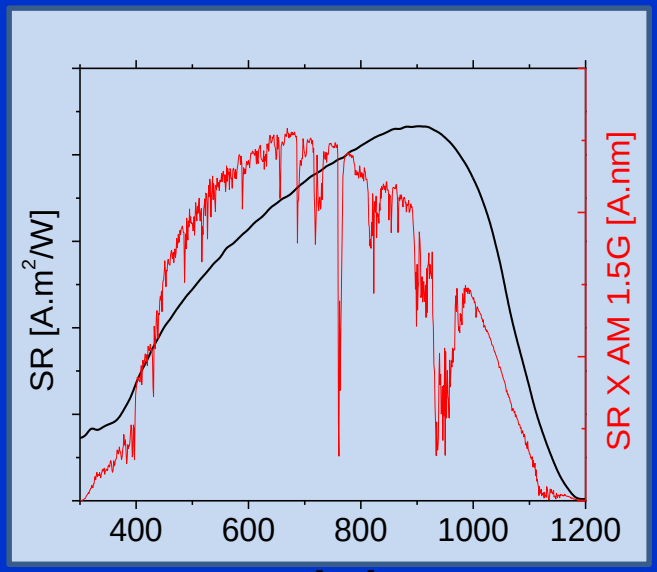
Developing, utilizing, and combining aspects of two techniques for measuring a cell's absolute spectral responsivity (SR)



Monochromator-based SR System



LED-based SR System



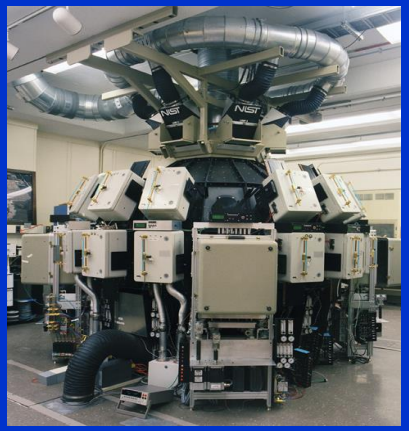
I_{sc} for AM 1.5

Reference Cell Calibrations with SI-Traceability

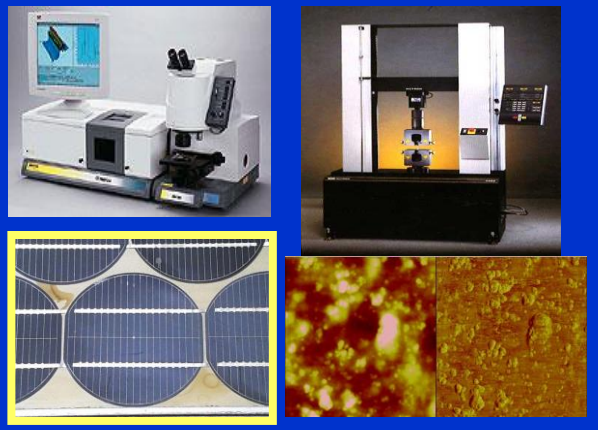
Advancing Service Life Prediction of Polymers Used in PV Systems

NIST is advancing the understanding of failure mechanisms of polymeric materials utilized in solar cell assemblies

- Engage industry partners and end-users.
- Fabricate a state-of-the-art PV accelerated weathering facility.
- Define, design, and expose PV materials, components and mini-modules.
- Characterize degradation mechanism under multiple simultaneous stresses.
- Develop and validate service life prediction models.



NIST SPHERE for Accelerated Weatherability Testing



Degradation Measurement and Failure Analysis

Linking Laboratory and Field

Total Effective Dosage Model

$$D_{total}(t) = \int_0^t \int_{\lambda_{min}}^{\lambda_{max}} E_o(\lambda,t)(1-e^{-A(\lambda)})\phi(\lambda)\,d\lambda\,dt$$

Cumulative Damage Prediction Model

$$Damage_{CUM}(t) = \sum_{i=0}^{t} \Delta D(t)$$

Service Life Prediction Models

Underwriters Laboratories, 3M, Arkema, DuPont, Daikin, First Solar

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Solar Photovoltaic Test Beds

PV performance and meteorological data from field-installed solar systems

Characterize solar cells & modules => improve module ratings and computer models

GREENHOUSE GAS AND CLIMATE SCIENCE MEASUREMENTS PROGRAM

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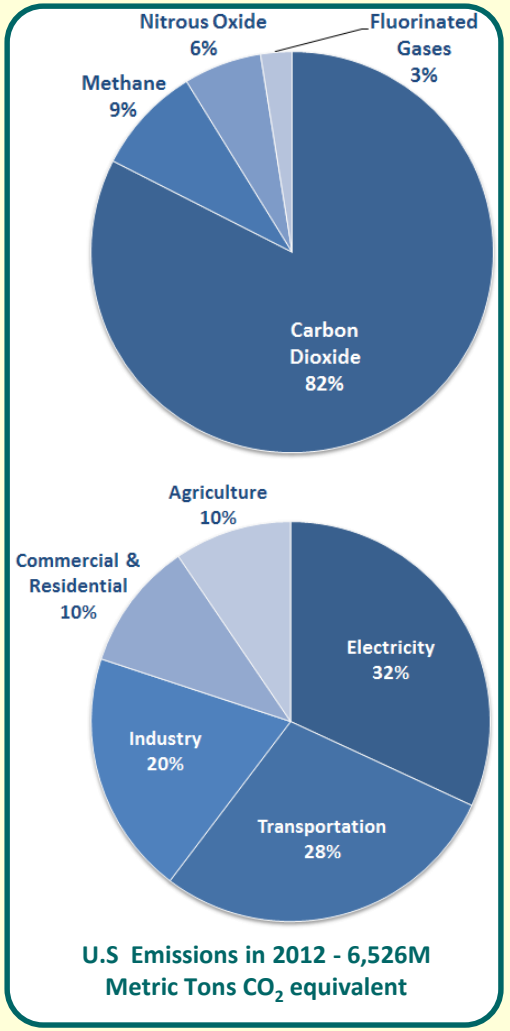
Greenhouse Gas and Climate Science Measurements Program



Objectives:

- **Develop advanced measurement tools and standards to improve accuracy capabilities for:**
  - **Greenhouse gas emissions inventory data**
    - Improving emissions measurement & reporting accuracy
    - Independent methodologies to diagnose and verify emissions data both nationally and internationally
    - Applications focused on cities and metropolitan areas
  - **Remote observations, both satellite and surface-based**
    - Extend measurement science and tools underpinning advances in understanding and description of Earth's climate and its change drivers

NIST Greenhouse Gas and Climate Science Measurements Program Components

- **Stationary/Point Source Metrology**
  - Increase accuracy of Continuous Emission Monitoring technology
    - Flow Test Beds - smoke stack simulators
- **Geospatially Distributed GHG Source Metrology**
  - Measurement Tools and Test Beds Characterizing Emission in Urban GHG Concentration Domes
    - Compare methods to Reconcile GHG Emission Inventory Accuracy – Bottom-up vs. Top-Down
    - Measurement Tools and Test beds for Urban GHG domes
    - An International Greenhouse Gas Metrology Framework Supporting Inventory Diagnosis and MRV Based on Megacity Test Beds

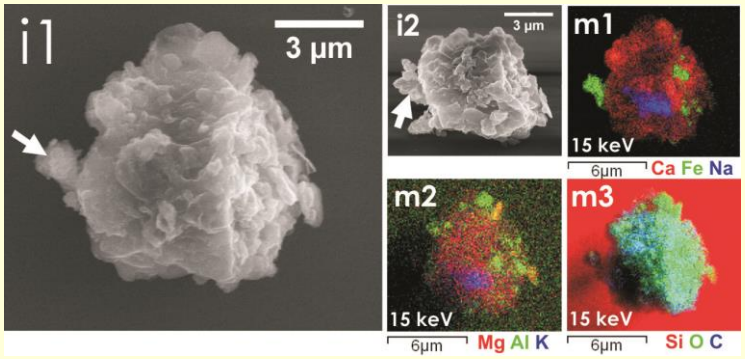
- **Measurement Tools, Standards, and Ref. Data**
  - GHG Concentration Standards
  - Spectroscopic Reference Data
  - Surface Air Temperature Assessment
  - Atmospheric Flux Measurement Tools
- **Climate Science Measurements - Advanced Satellite Calibration Standards**
  - Microwave Observing Standards
  - Advanced Optical Radiometric Methods
  - TOA and Surface Solar Irradiance
  - Surface Albedo Standards
- **Measurement Science of Carbonaceous Aerosols**
  - Advanced Optical Property Measurements
  - Development of Reference Materials

Carbonaceous Aerosol Measurement Challenges

Aerosols present significant measurement challenges because they are a **Mixture** of particles in a gas with complex and diverse characteristics.

- Phase: Solid or liquid or both
- Size: 10 nm to 1 µm
- Mass: fg to ng
- Shape: all sorts
- Composition: OC, EC/OC, Sulfate, Nitrate, Ammonium, Mineral dust, etc…

- Urban Concentration:
  10^2 to 10^5 particles cm^{-3}
  1 to 100 µg m^{-3}

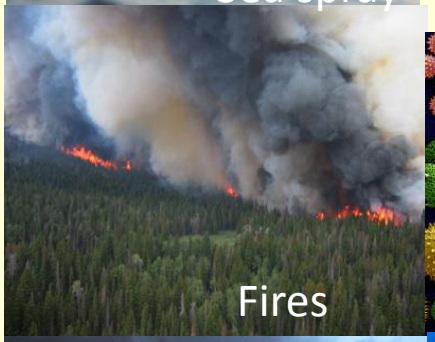


Electron image & element maps particle sample – Los Angeles 2004

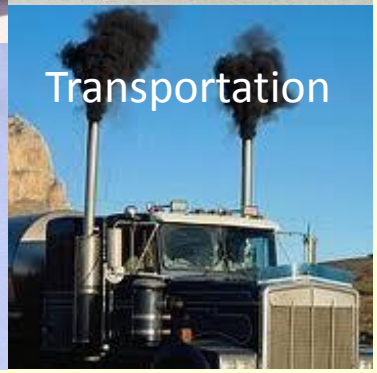
- Tropospheric Lifetime - ~ 1 week
- Transport distance –
  ½ way around the world

Sources

Natural



Anthropogenic

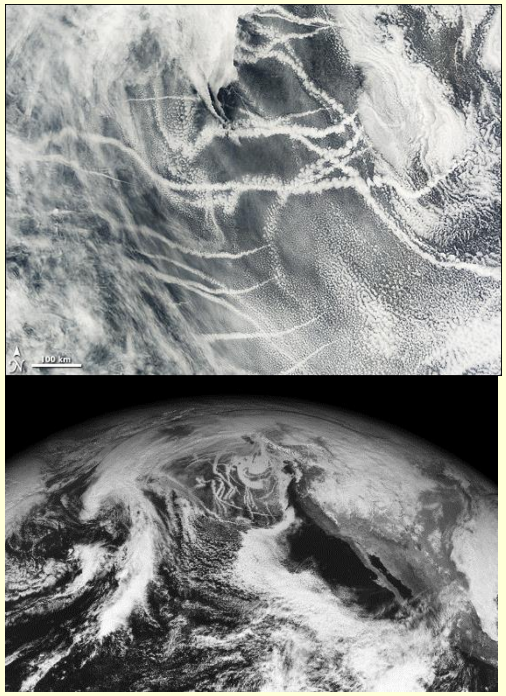


Aerosol impacts

- Warms Climate Via Absorption – Broadband
- Cools Climate Via Cloud And Condensation Processes
- Changes Surface Albedo
- Affects Local And Global Scale Weather And Air Quality

14 ug/m3 loading - Acadia, ME - Out of EPA attainment

886 ug/m3 loading - Beijing, China



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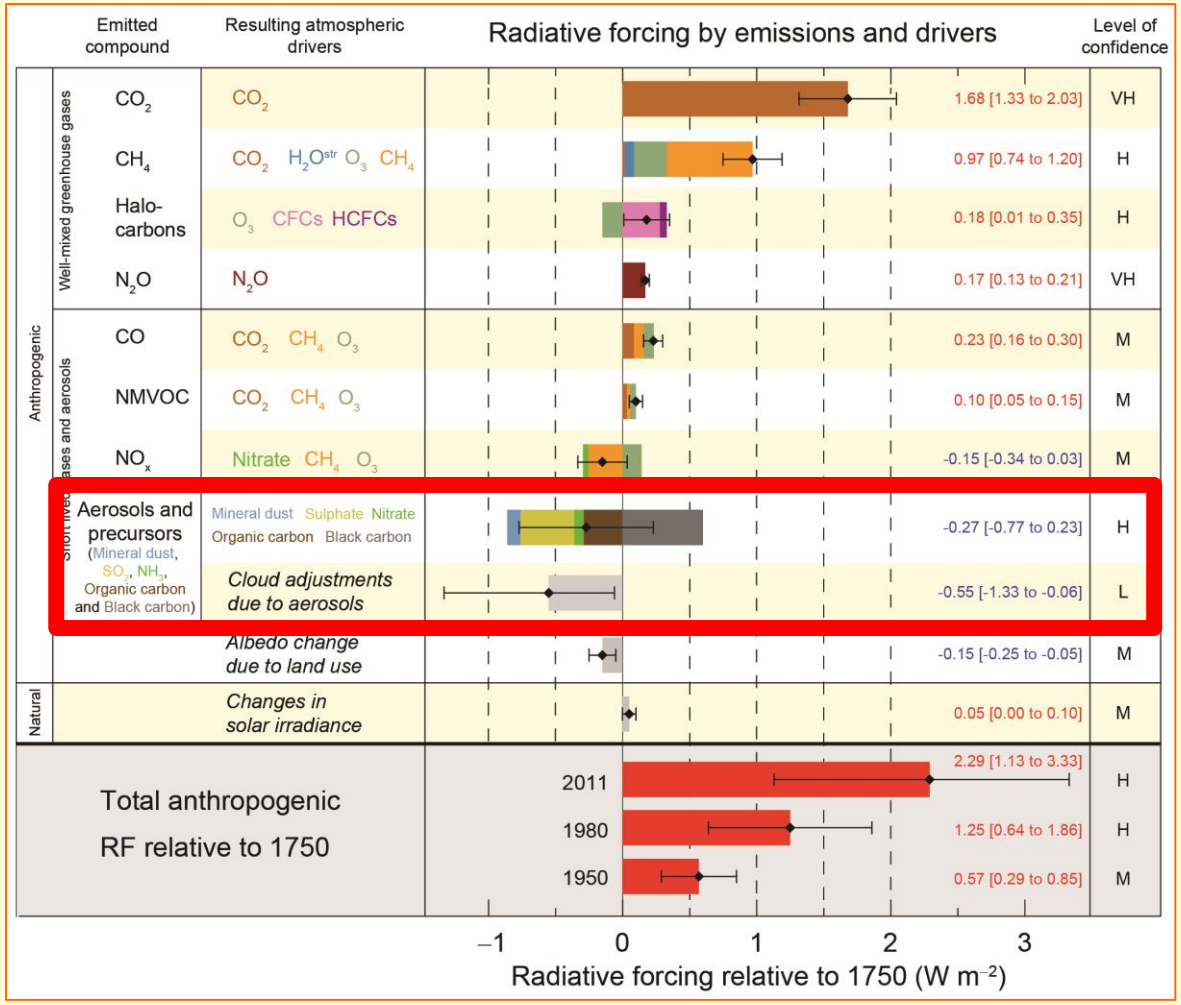
Radiative Forcing Attributed to Aerosols



Aerosols:

- **2nd leading cause for radiative forcing**
- **represents ≈75% of forcing uncertainty**

UN IPCC 2013

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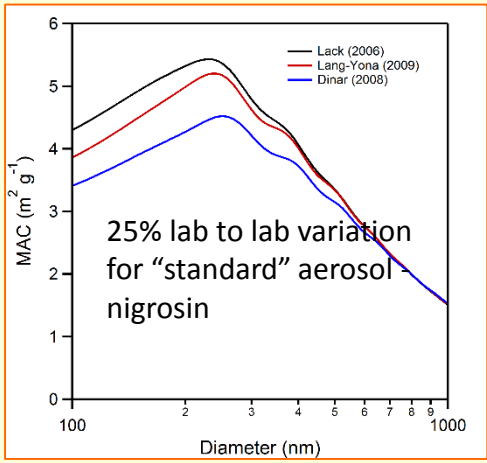
Needs of the Communities

Improved measurements through:

- Traceable Measurements
- Reference Materials
- Data for Materials with Known Properties
- Methods for Evaluating Instrument Performance
- Improved Instrumentation – Specificity and Sensitivity
- Terminology Clarification
- Cross Disciplinary Understanding of Aerosols, Their Measurement and Underlying Chemistry



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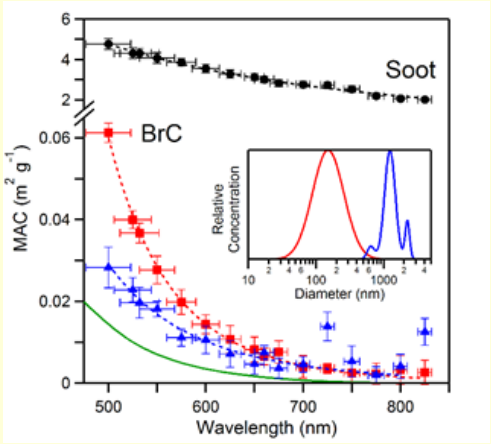
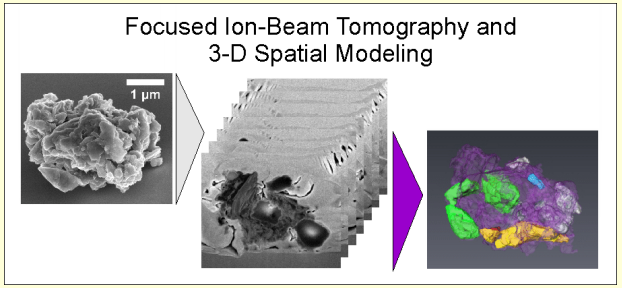
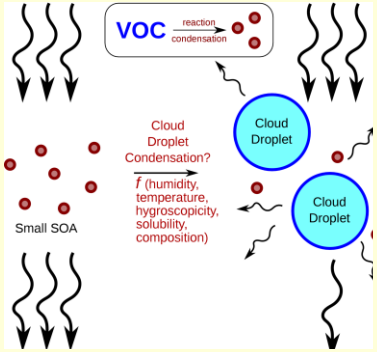
NIST Aerosol projects

- **Characterize radiative properties of black and brown carbon systems**
  - **Develop and apply new optical measurement capabilities**
  - **Correlate optical properties with chemical composition**
  - **Develop a transferable aerosol with known optical properties**
- Microanalysis of heterogeneous aerosols
  - Determine shape, composition, & internal structure
  - Correlate optical properties based on 3-D spatial models
- Organic aerosol chemistry impacting solar radiation
  - Use a photochemical flow reactor to elucidate key VOC oxidation reactions producing chromophores and particulates
  - Characterize droplet formation propensity



Mass absorption of soot, brown carbon, and BrC Solution





Atmospheric aerosol processes

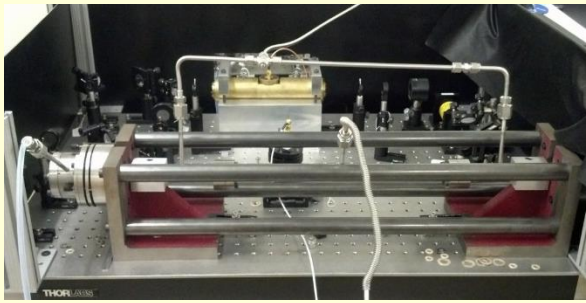
Tools & Expertise

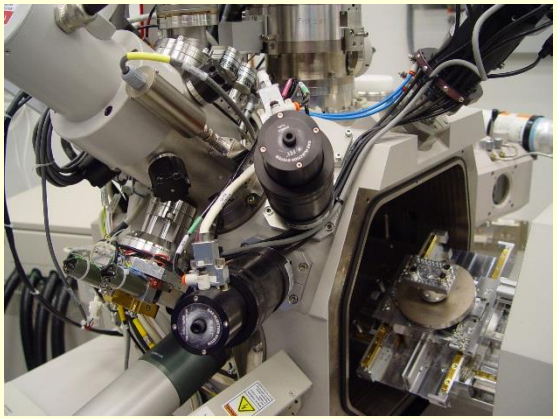
Particle generation
Soot & spray generation
Flow reactor
Conditioning tools

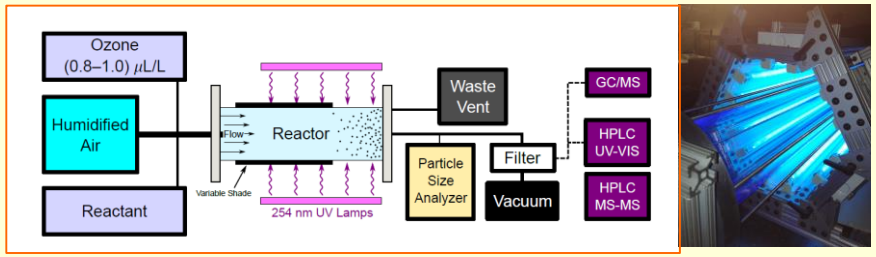
Particle characterization
Size - Differential mobility analyzer
Mass - Aerosol particle mass analyzer
Number - Condensation particle counter
Cloud condensation nuclei counter

Chemical analysis including 3-D structure and composition
High performance liquid chromatography
Tandem mass spectrometer
Focused ion beam scanning electron microscope with X-ray detection
Transmission electron microscopy
Electron backscatter diffraction
Inductively coupled plasma mass spectrometer

Optical properties
Cavity ring down spectrometer
Photoacoustic absorption spectrometer


Cavity ringdown and photoacoustic spectrometers


FEI Nova NanoLab 600 focused ion-beam scanning electron microscope



Photochemical Flow Reactor to Study Extensive Oxidation of Organic Compounds

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Muchas Gracias
Thank You

Questions or Discussion ?